Kepler/K2 in the Context of Future Exoplanet Missions

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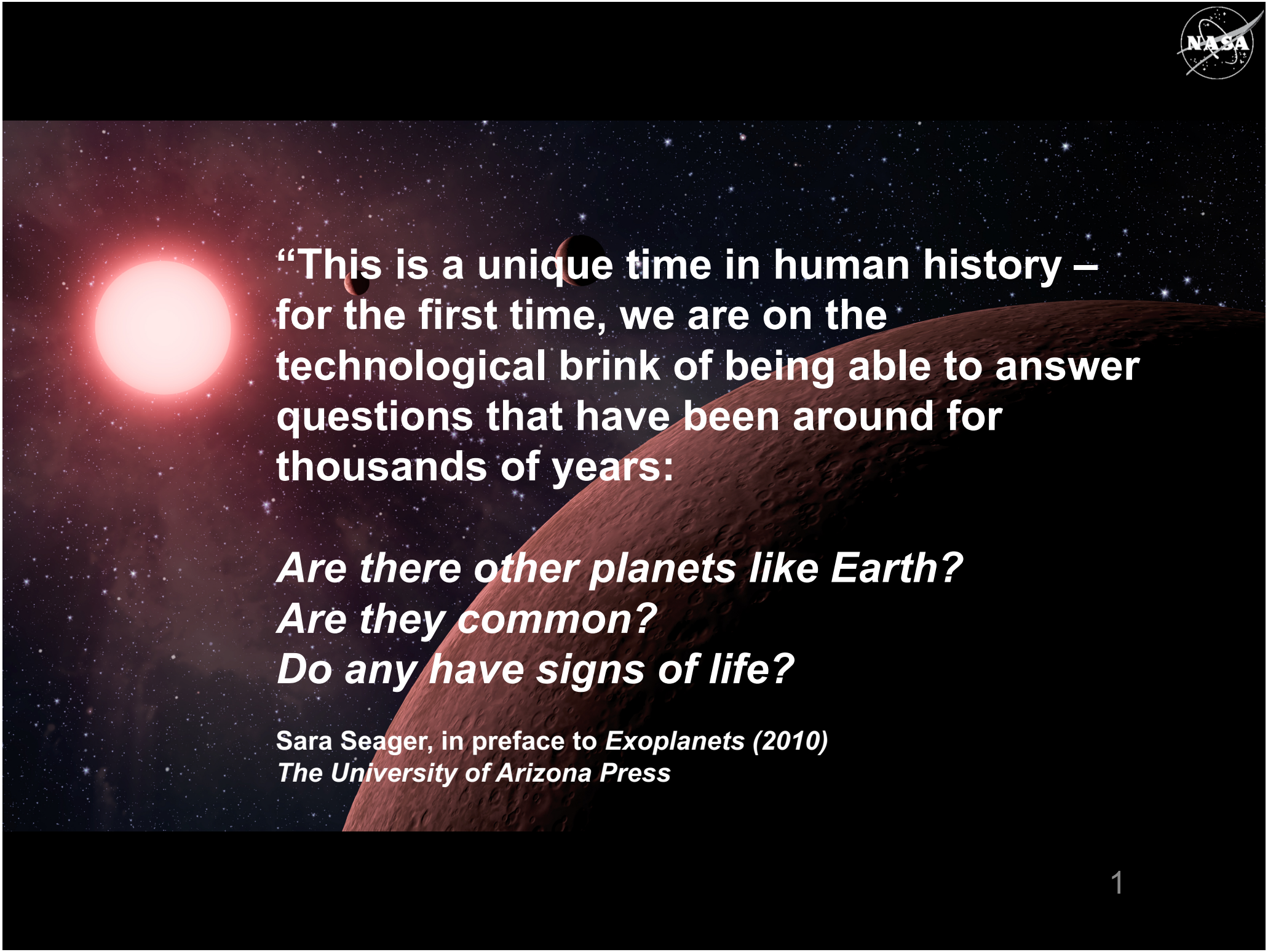
Jet Propulsion Laboratory
California Institute of Technology
URS266683

June 23, 2017
Kepler/K2 SciCon IV
Mountain View, CA

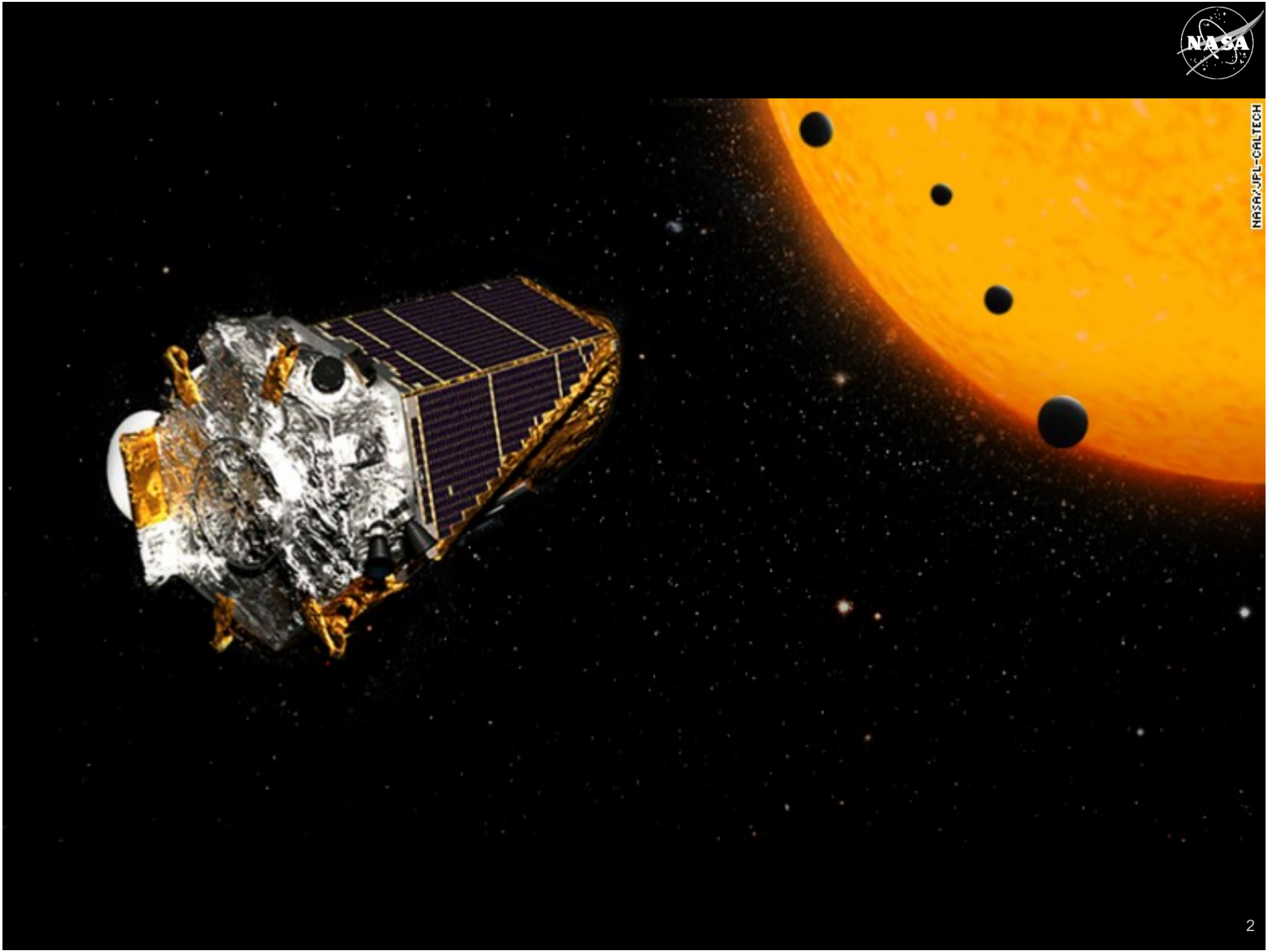
Artist concept of Kepler-16b
Credit: NASA/JPL-Caltech/T. Pyle



"This is a unique time in human history – for the first time, we are on the technological brink of being able to answer questions that have been around for thousands of years:

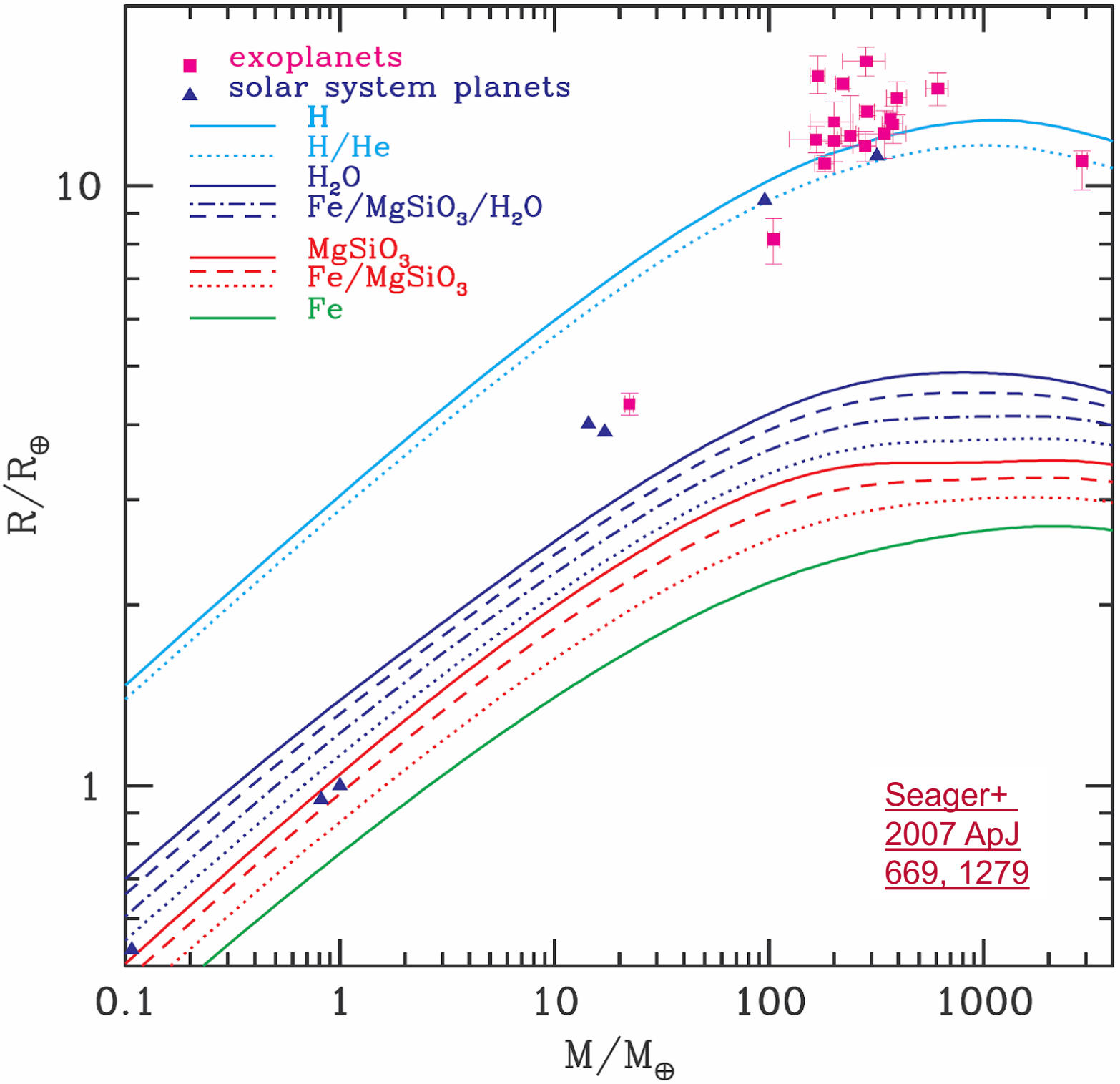
Are there other planets like Earth?
Are they common?
Do any have signs of life?

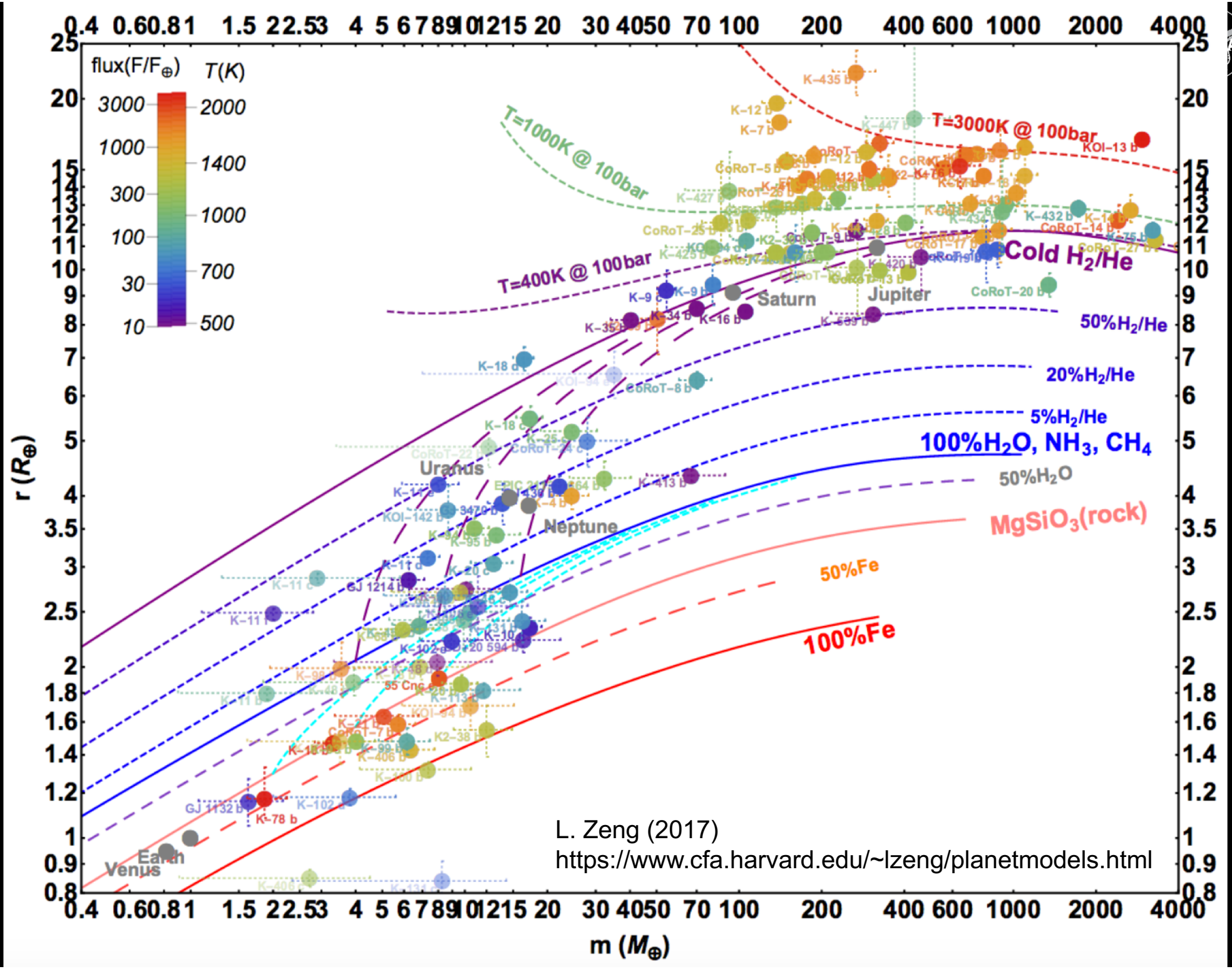
Sara Seager, in preface to *Exoplanets (2010)*
The University of Arizona Press


NASA/JPL-CALTECH

Mass vs. Radius

10 years ago(!)





L. Zeng (2017)
https://www.cfa.harvard.edu/~lzeng/planetmodels.html

Exoplanets:
Detections by Discovery Year

1989-2016

Plots generated Oct. 11, 2016

NASA Exoplanet Exploration Program

Astrophysics Division, NASA Science Mission Directorate

NASA's search for habitable planets and life beyond our solar system

Program purpose described in
2014 NASA Science Plan

1. **Discover planets around other stars**
2. **Characterize their properties**
3. **Identify candidates that could harbor life**

ExEP serves the science community and NASA by implementing NASA's space science vision for exoplanets

https://exoplanets.nasa.gov

Exoplanet Missions

WFIRST

JWST[2]

TESS

PLATO

Kepler

CHEOPS

New Worlds Telescope

Spitzer

Gaia

Hubble[1]

CoRoT[3]

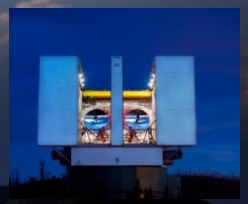
Habitable Exoplanet Imager

LUVOIR

Origins Space Telescope

NASA Missions

ESA/European Missions



Large Binocular Telescope Interferometer

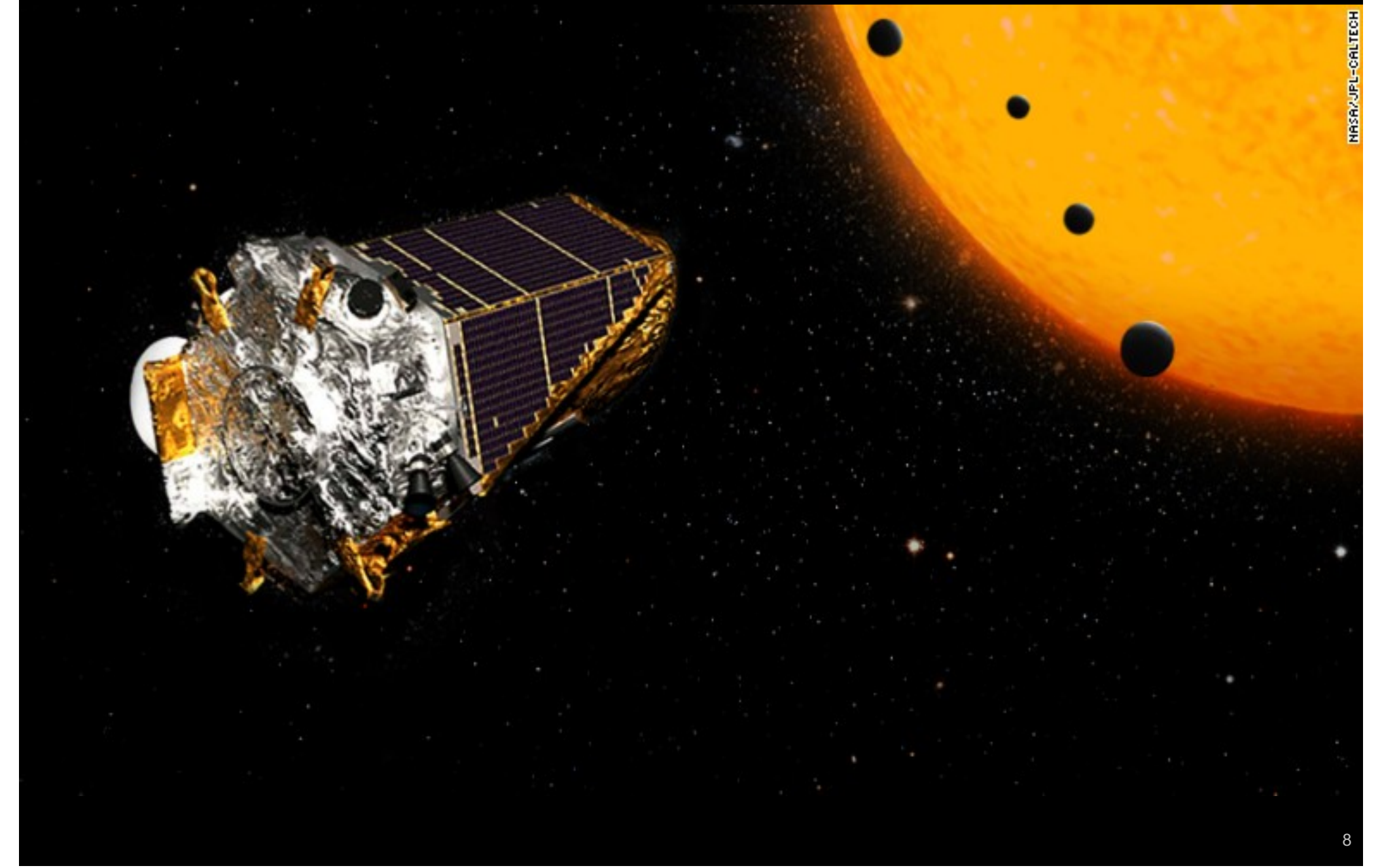
NN-EXPLORE

W. M. Keck Observatory

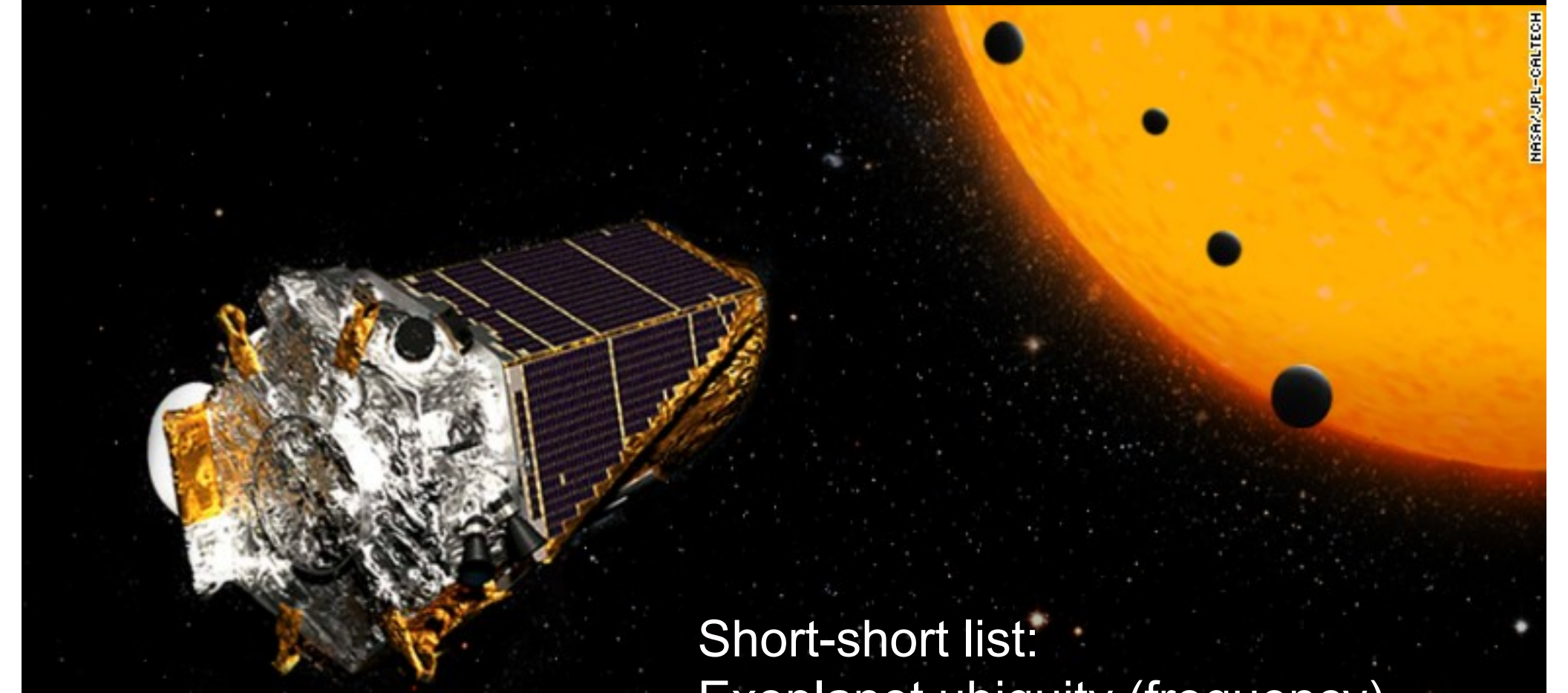
[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA

Ground Telescopes with NASA participation

Kepler highlights



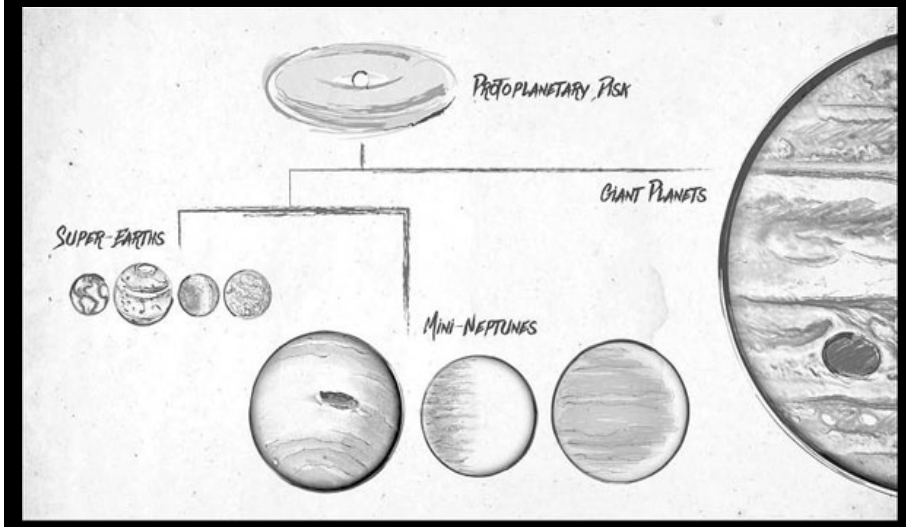
Kepler highlights



Short-short list:
Exoplanet ubiquity (frequency)
Exoplanet variety (types)
Earth-size planets in Hab Zones
Stellar astrophysics (know thy star)

Exoplanets vs. Cockroaches

"It's like if you see one cockroach, you've seen ten—they're hiding." - John Johnson



"All the News That's Fit to Print"

The New York Times

Late Edition

Today, patchy morning fog, partly sunny, warm, high 64. Tonight, mostly cloudy, mild, low 52. Tomorrow, clouds and sunshine, showers, high 66. Weather map is on Page B9.

VOL. CLXVI ... No. 57,517 © 2017 The New York Times Company NEW YORK, THURSDAY, FEBRUARY 23, 2017 $2.50

A rendering of newly discovered Earth-size planets orbiting a dwarf star named Trappist-1 about 40 light-years from Earth. Some of them could have surface water.

TRUMP RESCINDS OBAMA DIRECTIVE ON BATHROOM USE

ENTERING CULTURE WARS

Question of Transgender Rights Splits DeVos and Sessions

This article is by Jeremy W. Peters, Jo Becker and Julie Hirschfeld Davis.

WASHINGTON — President Trump on Wednesday rescinded protections for transgender students that had allowed them to use bathrooms corresponding with their gender identity, overruling his own education secretary and placing his administration firmly in the middle of the culture wars that many Republicans have tried to leave behind.

In a joint letter, the top civil rights officials from the Justice Department and the Education Department rejected the Obama administration's position that nondiscrimination laws require schools to allow transgender students to use the bathrooms of their choice.

This directive, they said, was improperly and arbitrarily devised, "without due regard for the primary role of the states and lo-

Circling a Star Not Far Away, 7 Shots at Life

By KENNETH CHANG

Uber's Culture Of Gutsiness Under Review

By MIKE ISAAC

Migrants Hide, Fearing Capture on 'Any Corner'

By VIVIAN YEE

No going to church, no going to the store. No doctor's appointments for some, no school for others. No driving, period — not

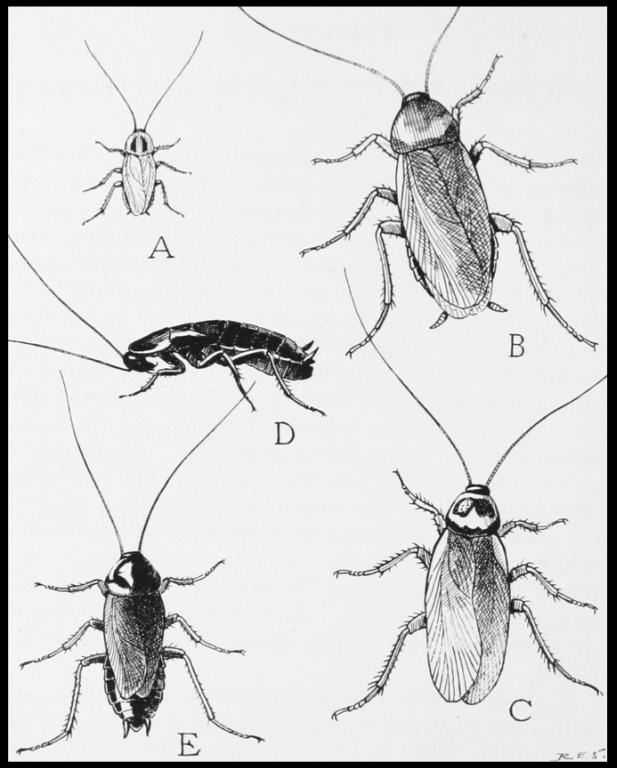
IMMIGRATION A police department worries a crackdown will harm work to fight gangs. PAGE A8

MEXICO The secretary of state pays a visit at a time of rising

duras.

If deportation has always been a threat on paper for the 11 million people living in the country illegally, it rarely imperiled those who did not commit serious crimes. But with the Trump ad-

- Very common, inclined to aggregate
- Ancient
- Hardy
- High resistance to radiation
- Factor of ~40x size range
- Capable of rapid population growth
- Test limits of habitability
- Capable of digesting paper



Only ~30 cockroach species out of ~4600 associated w/ human habitats ("pests")

NASA/Ames Research Center/JPL-Caltech/Tim Pyle

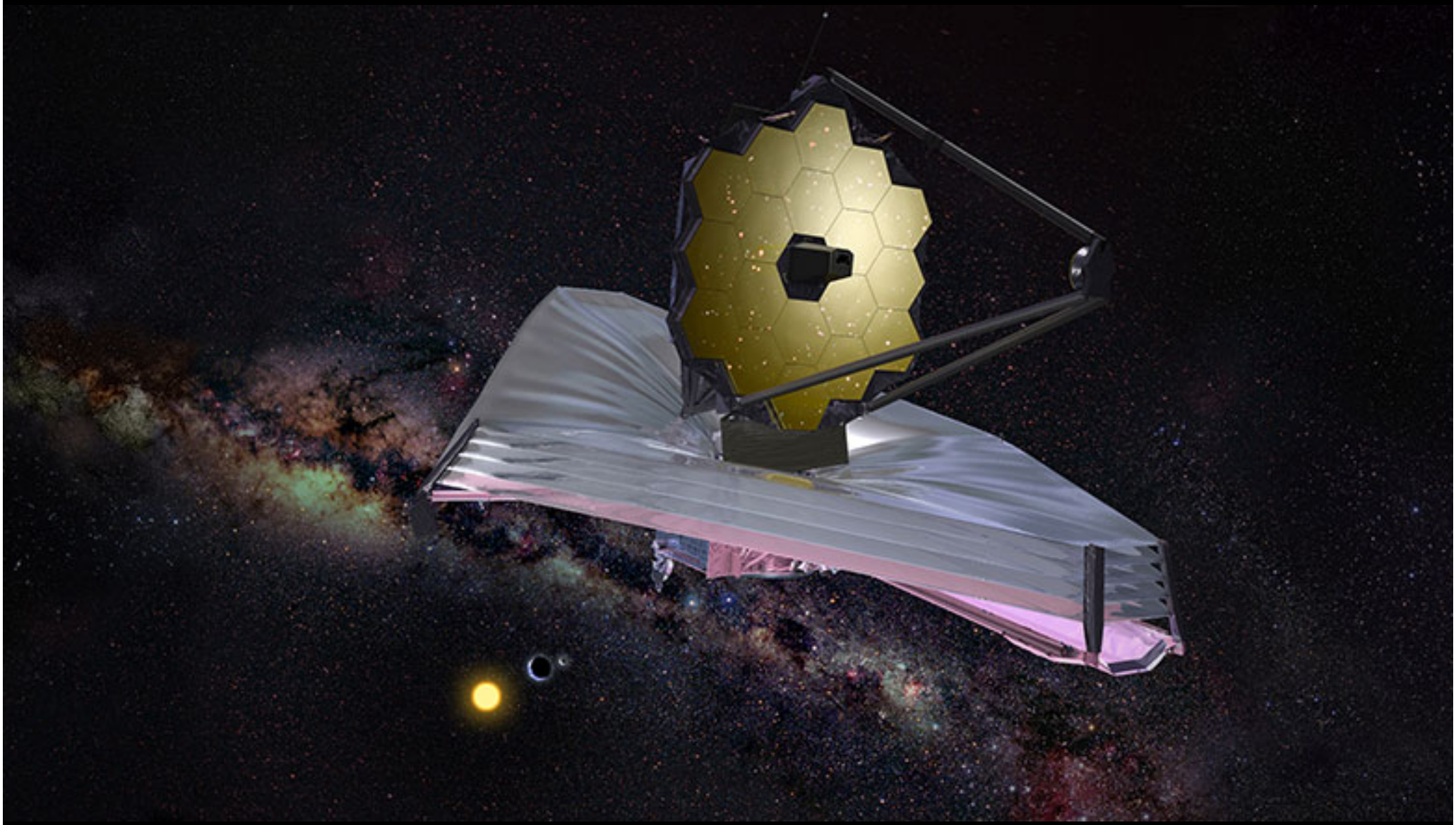
R.E. Snodgrass, Wikimedia Commons

Science Questions and Required Data for Direct Imaging Exoplanet Missions

	Science Questions	Targets	Data Type and Quality
Planetary Sys. Properties	A1 Planetary System Diversity	Statistical Studies of Planetary Systems	1) Multi-epoch Imaging: Planetary Orbits 2) Phot/Spec/RV/Astrom: Planet Masses
	A2 Planetsimal Belts, Exo-Zodi Disks, Formation of Planetary Systems?		1) O/IR Imaging: Locations of Dust Belts 2) Planet masses and orbits (RV, Astrom.)
Planet Properties	B1 Rotation and Obliquitiy	Studies of Individual Planets	1) Time-Resolved Phot/Spec 2) High-Res Spec. for Rotational Period 3) Lightcurves at Multiple Orb. Phases: Obliquity
	B2 Which Rocky Planets have Surface Liquid Water?		1) Time-Resolved Obs: Ocean Glint 2) Rotational Mapping: Oceans 3) Water Line Spectroscopy
	B3 Aerosols and Composition in Giant Planets		1) Low-res., broad range spectroscopy 2) Time-resolved Phot. for Cloud Mapping 3) Optical/Near-IR Colors
	B4 Terrestrial Planets Atmospheric Composition		1) Low-res., broad range spectroscopy 2) Optical/Near-IR colors 3) Planet masses and orbits
Planetary Processes	C1 What Processes/Properties Influence Atmospheric Circulation?	Statistical Studies of Groups of Planets	1) Multi-epoch, moderate to high-res. NIR spectroscopy
	C2 Key evolutionary pathways for rocky planets?		1) Atmospheric Characterization (B4) 2) Planet Mass
	C3 Geological Activity/Interior Processes		1) Atmospheric Characterization (B4) AND 2) Surface mapping (B2) 3) Planet Mass (RV or astrom.)

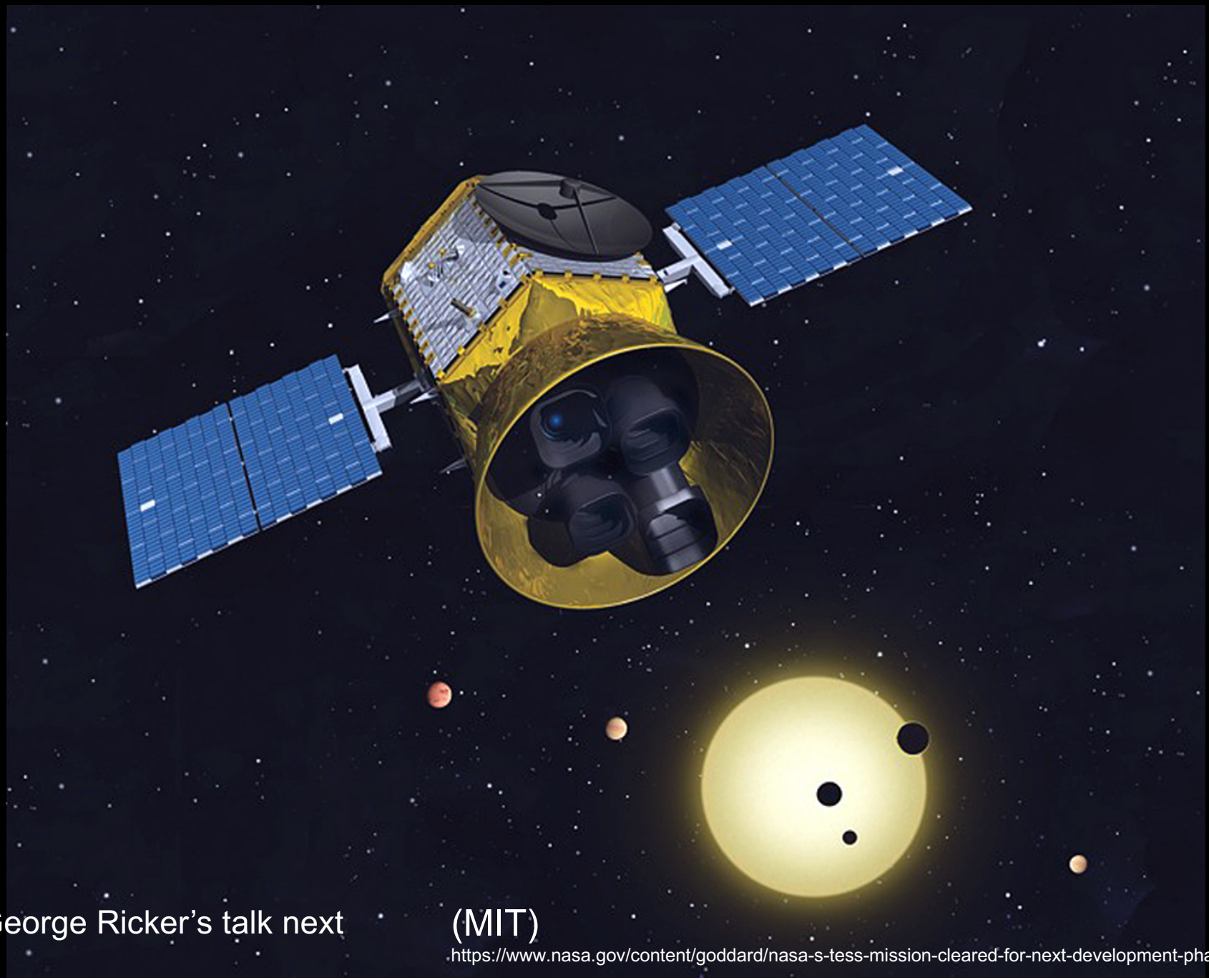
EXOPAG/SAG15 Team and Daniel Apai / Univ. Arizona

JWST



https://jwst.stsci.edu/science

TESS (NASA Explorer Program)



See George Ricker's talk next (MIT)

https://www.nasa.gov/content/goddard/nasa-s-tess-mission-cleared-for-next-development-phase

Wide Field Infrared Survey Telescope (WFIRST)

Dark Energy, Exoplanets via two main methods

- WFIRST in Phase A
- All technology milestones were met on time
  - Five for IR Detector, now at TRL 6
  - Nine for Coronagraph, now at TRL 5
- Actively studying making WFIRST starshade-ready (not baseline).
- Reviews for SRR/MDR: delayed to allow independent external review
- https://www.nasa.gov/feature/nasa-taking-a-fresh-look-at-next-generation-space-telescope-plans

Credit: NASA/GSFC

Astrophysics Probe Mission Concepts

Announced by NASA March 20

- 10 proposals selected for mission concept studies
  - PI-led science team
  - NASA mission design labs at JPL and GSFC.
  - Results will be provided to 2020 Decadal Committee

- 2 exoplanet studies were “partially” selected:
  - Peter Plavchan: develop the science case for space PRV mission.
  - Sara Seager: update starshade rendezvous mission concept.

- The ExEP and PCOS / COR programs are facilitating all ten studies by supporting the PIs throughout the study and more specifically assisting the PIs in executing their design lab studies.

TEAMX Jet Propulsion Laboratory

Goddard Space Flight Center Integrated Design Center

NN-EXPLORE

Partnership for Exoplanet Discovery and Characterization

- Extreme precision radial velocity spectrometer (<0.5 m/s) for WIYN telescope
  - Laser frequency comb reference
- Development milestones:
  - Passed the Instrument Detailed Design Review in November 2016
  - Passed the Port Adapter Detailed Design review in May 2017
  - Instrument commissioning by August 2019
- Ongoing Guest Observer program using 40% NOAO share of telescope time for exoplanet research with existing instruments. Proposals due in late September.
- Re: John Callas' talk in Wed. splinter session

NN-Explore Exoplanet Investigations with Doppler Spectroscopy

PennState

PI: S. Mahadevan

NOAO 3.5-m WIYN Telescope, Kitt Peak National Observatory, Arizona

Possible New Worlds Exoplanet Telescopes

(mid 2030s; work outside ExEP)

- **Large Ultra-Violet Optical InfraRed Telescope (LUVOIR)**
  - Coronagraphic imaging with deployed/segmented primary mirror
  - Large apertures & exoplanet survey samples
  - 5 instruments, equal weighting to exoplanets & general astrophysics
- **Habitable Exoplanet Mission (HabEx)**
  - Coronagraph & starshade imaging with monolithic, off-axis telescope
  - Smaller apertures & exoplanet survey samples
  - 3 instruments, including UV spectrometer & general astrophysics camera
- **Origins Space Telescope (OST)**
  - mid/far-infrared flagship concept
  - Primary exoplanet science case is transit spectroscopy
  - New exoplanet working group co-Chaired by Lisa Kaltenegger (Cornell) & Kevin Stevenson (STScI)

Two community studies of potential future missions to find/characterize ExoEarths : Habitable Exoplanet Mission (HabEx) and Large UltraViolet Optical near-IR (LUVOIR) surveyor

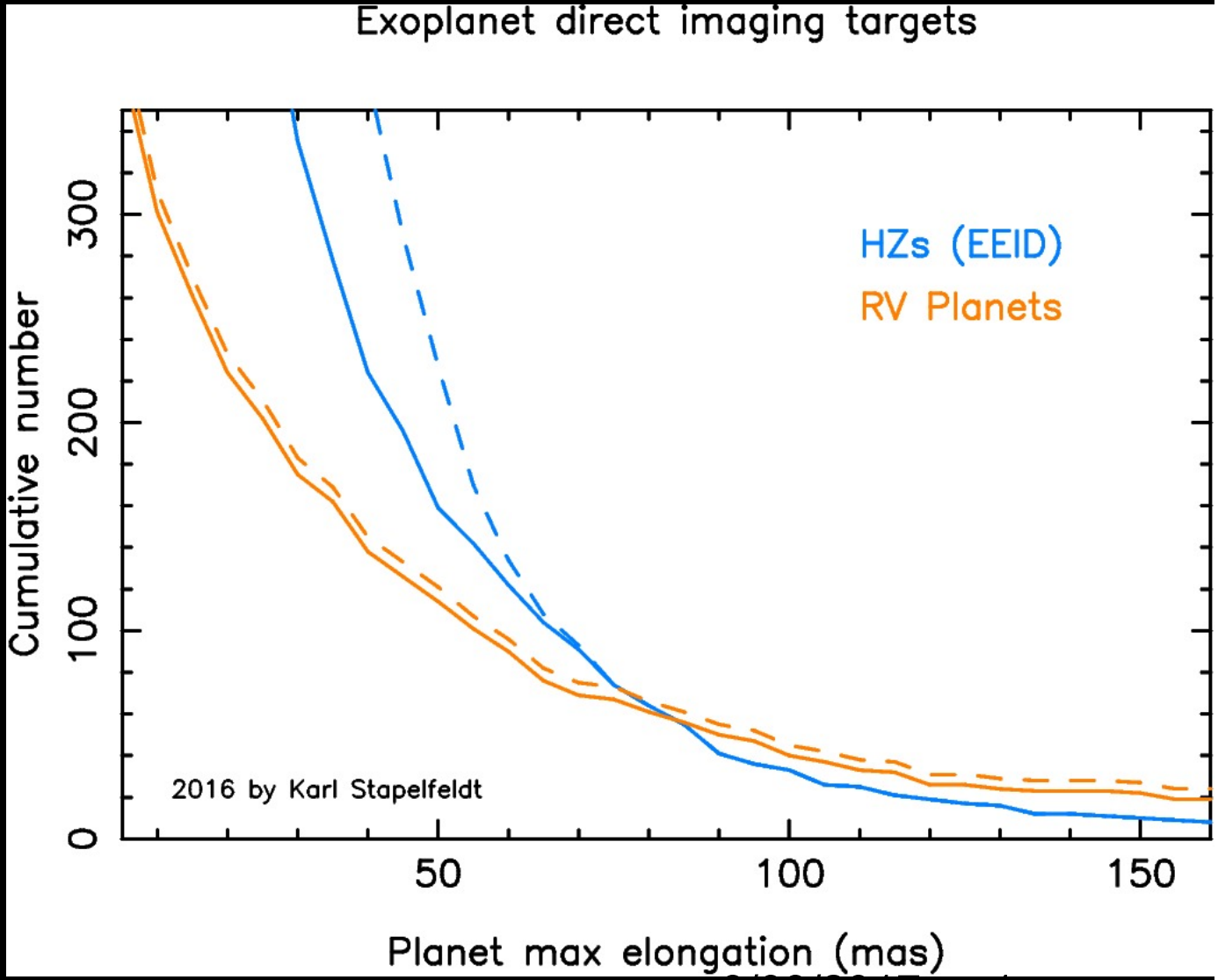
- Both have goal of studying Earthlike planets in reflected light; they differ in levels of ambition, cost, and technical readiness
  - HabEx to "*search for*" signs of habitability and biosignatures
  - LUVOIR to "*constrain the frequency of*" habitability and biosignatures = larger statistical survey of exoEarths, larger aperture
- HabEx to focus on exoplanets, "best effort" on general astrophysics. Starshade. Study led by JPL/Caltech
- LUVOIR gives equal priority to exoplanets and cosmic origins science, is HST-like, an expansive vision. Study led by NASA Goddard.
- Interim reports late 2017; final reports early 2019. Next Astrophysics Decadal Survey to decide if one of them might go forward

Capabilities of future space telescopes for exoplanet imaging characterization - target samples

Cumulative number of known RV planets and HZs that can potentially be accessed, as a function of how close to the star one can look.

Values reflect local distribution of star types & their distances from the Sun

Accessing 100 HZs will require looking as close as 70 mas, which at 0.55 μm could require a ~5 m telescope



Steps that will enable direct imaging and spectra of habitable exoplanets

- Understand the frequency of HZ rocky planets
- Measure the astronomical backgrounds
- Make precursor and follow-up observations to measure exoplanet masses and orbits, where possible
- Measure host star properties that affect habitability
- Develop our understanding of exoplanet atmospheres, biosignatures, and biosignature false positives
- Ready the starlight suppression technology
- Close in on the mission architecture

Frequency of rocky planets : avenues for progress beyond

- Independent community analyses of Kepler planet occurrence rates; synthesis of those results
- Learn what we can from longest-period planets found w/TESS in its continuous viewing zones
- Synthesis of exoplanet demographics from transits, RV, and microlensing results

Summary status: a lot of effort has been invested to address this question. Is there more we can do ? The uncertainty on $\eta_{\oplus}$ could affect decadal choices.

NASA Auth Bill S.442

Report due from Nat'l Acad. 9/2018

SEC. 508. EXTRASOLAR PLANET EXPLORATION STRATEGY.

(a) STRATEGY.—

(1) IN GENERAL.—The Administrator shall enter into an arrangement with the National Academies to develop a science strategy for the study and exploration of extrasolar planets, including the use of the Transiting Exoplanet Survey Satellite, the James Webb Space Telescope, a potential Wide-Field Infrared Survey Telescope mission, or any other telescope, spacecraft, or instrument, as appropriate.

(2) REQUIREMENTS.—The strategy shall—

(A) outline key scientific questions;

(B) identify the most promising research in the field;

(C) indicate the extent to which the mission priorities in existing decadal surveys address the key extrasolar planet research and exploration goals;

(D) identify opportunities for coordination with international partners, commercial partners, and not-for-profit partners; and

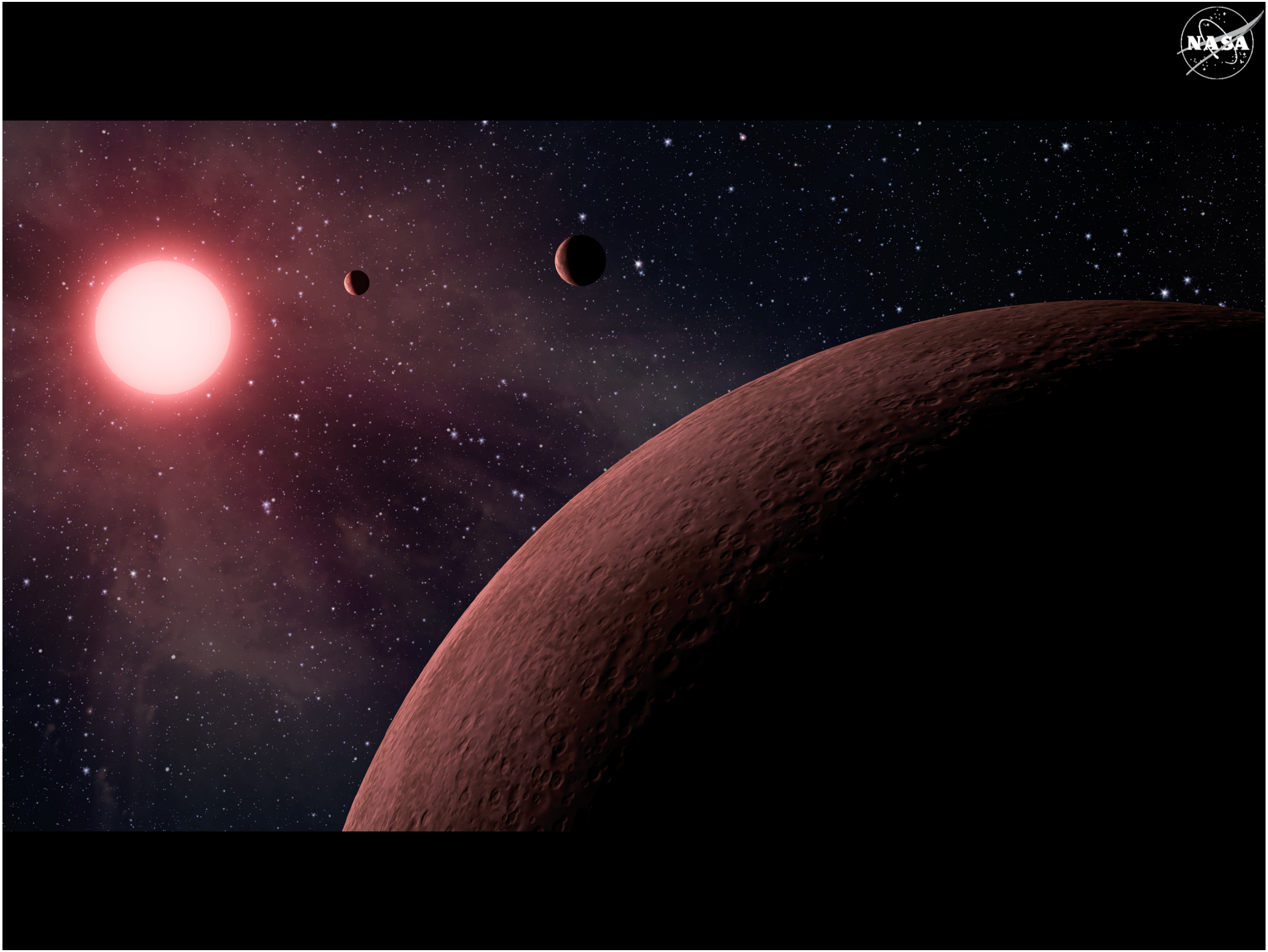
(E) make recommendations regarding the activities under subparagraphs (A) through (D), as appropriate.

(b) USE OF STRATEGY.—The Administrator shall use the strategy—

(1) to inform roadmaps, strategic plans, and other activities of the Administration as they relate to extrasolar planet research and exploration; and

(2) to provide a foundation for future activities and initiatives related to extrasolar planet research and exploration.

(c) REPORT TO CONGRESS.—Not later than 18 months after the date of enactment of this Act, the National Academies shall submit to the Administrator and to the appropriate committees of Congress a report containing the strategy developed under subsection (a).


NASA

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov